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TechDay on Combustion Engine Technology

1. Efficiency and driving pleasure: innovative V engines at Audi

V engines from the Four Rings have been around for 29 years – the 3.6-liter eight-cylinder engine made its debut in the Audi V8 in 1988. A 2.8-liter V6 followed two years later, in the Audi 100. Things then really took off in the 1990s: in 1997 the world's first V6 TDI appeared with the 2.5 TDI, followed in 1998 by the V8 TDI with a displacement of 3.3 liters. And in 2000 the V6 biturbo with 2.7 liters' displacement was a very special highlight: the 279 kW (380 hp) and 440 Nm *(324.5 lb-ft)* of torque driving the Audi RS 4 Avant set the bar at a totally new level in the midsize category.

Today, Audi uses V6 and V8 engines in all models based on the modular longitudinal platform, namely in the Audi A4, A5, A6, A8, Q5 and Q7 series. The V6 units – gasoline as well as diesel engines – operate with a displacement of 3.0 liters, and 4.0 liters in the case of the V8 engines. Their power output ranges from 160 kW (218 hp) to 445 kW (605 hp). The new 2.9 liter V6 engine in the Audi RS 5 (combined fuel consumption: 8.7 l/100 km *(27.0 US mpg);* combined CO_2 emissions: 197 g/km *(317.0 g/mi)*) is a special case. Owing to the increased power and therefore greater stress on the engine, the displacement was reduced by 0.1 liters.

1.1 Synergy effects in the Group: the V engine strategy

Audi and Porsche are closely collaborating on engine development: both premium brands employ the powerful and efficient V6 and V8 spark ignition engines in their models. "While Audi and Porsche have both hit the road in the upper premium market segment, they appeal to different customer groups," says Nikolai Ardey, Head of Powertrain Development at Audi. "In such a case it's only logical and consistent to have a strategy of the two brands sharing certain technologies and engineering tasks."

A broad range of technological modules is available for the supercharged V engines. Among other items, it features many identical and closely related solutions. Theses include the aluminum cast crankcase which is particularly light weight. The cylinder banks are set at an angle of 90 degrees relative to one another in the six-cylinder and eight-cylinder engines. For the V8 engines this is the classic bench angle, in the case of the V6 units a balancer shaft in the inside V compensates for the inertial torque.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

The 90-degree angle offers great advantages to customers. It affords a low center of gravity, which improves the driving dynamics. The standardized layout leads to many commonalities in the packaging inside the car, the positioning of the catalytic converters near the engine and in the installation locations of the ancillary units.

The development of the new generation of spark ignition V engines is underway in the same project building. The basis was provided by the V8 4.0 TFSI, which was designed in Neckarsulm and launched in 2012 (EA 824). Audi is responsible for the development of the new V6 spark ignition engines (code EA 839), while Porsche is handling the new V8 engine with the internal code EA 825. In its current top stage of development it drives the Panamera Turbo. Audi is also planning to implement it in the new generation of its A8 flagship.

The concept of the new V8 4.0 TFSI thus primarily originated from the previous Audi engine. The two twin scroll turbochargers lie in the inside V. The principle is as follows: the exhaust branches of the two cylinder banks run separately in the exhaust manifold and in the turbocharger housing, and only merge in front of the turbine wheel. This technology improves the flow characteristics so that the turbine responds more spontaneously. This makes a significant contribution to the early and powerful torque build-up. During partial-load operation, contour sleeves on the camshafts shut down four cylinders. This technology is based on the Audi valvelift system (AVS). A new feature is the extremely wear resistant iron coating of the cylinder walls applied by atmospheric plasma spraying. Another innovation is the oil circuit, with different gallery cross-sections for the block and cylinder heads. This quickly brings the oil to operating temperature, contributing to reduced fuel consumption.

A new feature for the V6 TFSI engines, the 3.0 TFSI and its high performance variant, the 2.9 TFSI, whose development Audi headed and which Porsche also uses, is the central location of the injectors in the combustion chambers. This feature can also be found in the 4.0 TFSI. At Porsche the engines are already running in the Panamera. At Audi the 3.0 TFSI drives several models. The RS 5 Coupé (combined fuel consumption: 8.7 l/100 km *(27.0 US mpg)*; combined CO_2 emissions: 197 g/km *(317.0 g/mi)*) is the first to employ the new 2.9 TFSI.

The central location of the injectors is an important component of the highly efficient B cycle combustion process, employed by both six-cylinder engines. Here too we have an Audi development based on the AVS. With its artificially shortened compression phase, the B cycle enables an engine process with a significantly higher base compression ratio. Combined with a power stroke that, while normal, is longer relative to the compression stroke, this allows for more efficient combustion and increased engine efficiency.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

Under partial load, the Audi valvelift system enables a very short intake aperture duration coupled with early closure of the intake valve. This shortens the intake phase. At higher loads, the system switches to a camshaft contour with a longer opening time and a larger valve stroke. The engine then operates with a normal compression ratio and maximum throughput.

In the V6 engines the turbochargers – one in the case of the 3.0 TFSI, two for the 2.9 TFSI – also lie in the inside V. This arrangement allows a compact design and minimizes flow loss, for spontaneous and direct engine response. Another specialty of the V6 TFSI engines is the exhaust manifold integrated in the cylinder head as an element of thermal management, so that the manifold is flushed by coolant. This helps the engine to heat up quickly. When the engine is warm, the system reduces the exhaust temperature. The result is lower fuel consumption, particularly during sporty driving. As with the 4.0 TFSI, the common-rail injection system builds up to 250 bar of pressure. This high pressure atomizes the fuel very finely to improve the combustion process.

The new V6 and V8 spark ignition engines are also suitable for hybridization – on a high and low voltage basis. At the launch of the next Audi A8 all engine systems will already have a mild-hybrid system on board, designed to operate in conjunction with a new 48-volt main electrical system.

The Hungarian plant at Győr, the largest engine factory in the world, produces the V6 TFSI units on its production line. The V8 TFSI engines are assembled at Porsche in the Zuffenhausen plant. In 2016, over 212,500 six-cylinder and more than 19,500 eight-cylinder engines were produced. The modular concept allows numerous parts to be shared – the oil pump module, the chain drive for the camshafts, the cover of the chain box and the rear sealing flange, to mention just a few. This leads to cost reductions and benefits for the production lines.

Audi has sole developmental responsibility for the diesel engines – the 3.0 TDI and the new 4.0 TDI. Porsche uses the self-igniting diesel engines in various evolutionary stages with slight modifications.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

1.2 Extensively improved: the new 3.0 TDI

Audi engineers have intensively further developed the new 3.0 TDI engine in many aspects. In the new Audi A5 and Q5 models the V6 diesel outputs 210 kW (286 hp) as well as 620 Nm *(457.3 lb-ft)* of torque (this engine version is not yet for sale. Since it still lacks an overall type approval, it is not subject to Directive 1999/94/EC), the latter from 1,500 to 3,000 revolutions per minute.

The six-cylinder engine draws power from a displacement of 2,967 cm^3 (bore x stroke 83.0 x 91.4 millimeters *(3.3 x 3.6 in)*). As with all V engines from Audi, its two banks lie at a 90-degree angle from one another. Inside the cylinder crankcase, made of high-strength cast iron with vermicular graphite, a balancer shaft rotates in order to reduce engine vibrations and to improve acoustics. The ignition pressure reaches the 200 bar mark over wide areas of the characteristic map.

The strict lightweight concept from Audi used for the crankshaft, the cylinder heads and the cylinder crankcase increases efficiency. Another aspect which plays a role here is reduced friction at the piston rings and pins thanks to the special cylinder wall coating. The use of a performance-regulated oil pump is also economically beneficial. The thermal management system segregates the circuits of the cylinder crankcase and cylinder heads from one another and supplies each with coolant after a cold start so as to bring the engine oil quickly up to its operating temperature. The cylinder heads have two-part water jackets for needs-based cooling. The oil cooler is integrated in the coolant flow of cylinder heads as needed.

The common-rail system generates up to 2,000 bar of injection pressure. The piezo injectors with their eight-hole nozzles can perform up to nine injections per work cycle. To optimize the air flow and the fuel mixture preparation, the intake ports (one each for swirl and the other for charging) and the exhaust ports have been modified relative to the predecessor engine. Both ports have lower flow resistance. The engine thereby acquires more spontaneous response characteristics and an even more homogeneous buildup of power.

The 3.0 TDI turbocharger operates with 2.3 bar relative boost pressure. The variable turbine geometry (VTG) is designed for low-loss flow. The low-pressure exhaust gas recirculation (EGR) removes the exhaust gas only downstream from the particulate filter and sends it through a radiator, for driving the turbocharger with the full exhaust-gas mass flow especially at medium and high loads.

The two emission control components are positioned very close to the engine. The first component is a large NOC oxidation catalytic converter (NO_x oxidation catalyst). It stores nitrogen oxides until it is full.

It is cleaned by enriching the fuel-air mixture in the engine. To minimize the related extra fuel consumption, the NOC kicks in especially at low exhaust temperatures. Once the operating temperature is reached, the second module of the system – the SCR-coated diesel particulate filter – takes care of NO_x conversion during intercity and highway driving (i.e. in the moderate rpm range).

The further developed 3.0 TDI is prepared for mild hybridization, as first introduced in mass production by Audi in 2017 for the A8. The 48-volt vehicle electrical system, which here powers a belt alternator starter (BAS), can also provide the energy for an electric powered compressor (EPC). It supports the turbocharger when starting off and accelerating from low engine speeds, with the benefits of high spontaneity and elasticity for customers.

1.3 The currently most powerful series-produced diesel from Audi: the V8 4.0 TDI

320 kW (435 hp) output, 900 Nm *(663.8 lb-ft)* torque from 1,000 to 3,250 rpm (combined fuel consumption: 9.3 – 7.2* l/100 km *(25.3 – 32.7 US mpg);* combined CO_2 emissions: 215 – 189 g/km* *(346.0 – 304.2 g/mi)*) – the 4.0 TDI is the most powerful V8 diesel engine from Audi. The V8 has the same stroke/bore ratio of 83.0 x 91.4 millimeters *(3.3 x 3.6 in)* as the V6; its displacement measures 3,956 cm^3. It accelerates the Audi SQ7 from 0 to 100 km/h *(62.1 mph)* in 4.8 seconds; the top speed of 250 km/h *(155.3 mph)* is electronically governed. In the NEDC, however, it consumes just 7.6 – 7.2 liters of diesel per 100 kilometers* *(30.9 – 32.7 US mpg)*, or 198 – 189 grams of CO_2 per kilometer* *(318.7 – 304.2 g/mi)*.

The 4.0 TDI is designed as a biturbo with sequential turbocharging, each turbocharger supplying both cylinder banks with fresh air. As is typical among Audi V engines, the turbochargers lie in the inside V – the short gas flow paths support the spontaneous response characteristics. They feature a variable turbine geometry and produce up to 2.4 bar of pressure (relative). They are controlled by the Audi valvelift system (AVS): electromagnetic actuators move sleeves onto the camshafts to switch on or off one of the two exhaust valves on each cylinder.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

The exhaust gas flows through separate channels in a two-flow manifold system – each valve supplies one of the two turbochargers. At low and intermediate loads and engine speeds, the AVS keeps one valve of the exhaust valves closed so that the full exhaust flow reaches the so-called “active” turbocharger. If the engine speed increases to the range between 2,200 and 2,700 rpm, the AVS opens the second valve in each case and then switches in the second turbocharger. The cooperation between the two turbochargers enables the 4.0 TDI to attain its maximum power.

Other AVS units lie on the intake camshafts, where they optimally charge the combustion chamber in any operating situation. At low engine speeds, they stabilize combustion, and at high rpms optimize the cylinder charging. The common-rail system generates up to 2,500 bar of injection pressure. This enables the specific output of the 4.0 TDI engine, while keeping emissions low in the partial load range through atomization of the fuel. The ignition pressure reaches up to 200 bar.

Continuously variable thermal management and selected measures in the crankshaft and camshaft drive keep friction low in the eight-cylinder engine. As with the V6 diesel engine, the combination of a NOx storage-type converter with an SCR converter integrated in the diesel particulate filter ensures effective and efficient exhaust treatment. A sound actuator in the exhaust system amplifies the sonorous V8 sound.

In the Audi SQ7 (combined fuel consumption: 7.6 – 7.2 l/100 km* *(30.9 – 32.7 US mpg)*; combined CO_2 emissions: 199 – 189 g/km* *(320.3 – 304.2 g/mi)*) the 4.0 TDI operates in conjunction with an electric powered compressor (EPC), which hauls its 7 kW of power from a 48-volt electrical subsystem. The EPC supports the two turbochargers when starting off and at low revs. The EPC lies in a bypass behind the charge air cooler. Instead of the turbine rotor, it integrates a compact electric motor that accelerates the compressor wheel to 70,000 revolutions per minute in less than 250 milliseconds. The very sporty SQ7 TDI can then benefit from even more spontaneous response characteristics and a more dynamic start-up performance from a stationary position.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

1.4 Versatile powerhouse: the new 3.0 TFSI

With the new 3.0 TFSI Audi is continuing the success story of its spark ignition engines. The turbocharged V6 combines powerful performance – high performance, lush torque at low revs, spontaneous response and sonorous sound – with a new level of efficiency. Developed in Neckarsulm, the engine made its debut in the new S models. But larger vehicle categories, including the Audi A8, will also be featuring the unit. During development, Audi engineers also designed the 3.0 TFSI for hybridization in the high and low voltage ranges. These engines are accordingly prepared for use of a belt alternator starter or an electric-powered compressor.

While the new six-cylinder engine still shares the bore size (84.5 mm *(3.3 in)*) and stroke (89.0 mm *(3.5 in)*) with its compressor supercharged predecessor, the cylinder gap has grown by 3 mm *(0.1 in)* to 93 mm *(3.7 in)*. The V6 turbo draws 260 kW (354 hp) of power from its 2,995 cm^3 displacement (combined fuel consumption: 8.5 – 7.3 l/100 km* *(27.7 – 32.2 US mpg)*; combined CO_2 emissions: 195 – 166 g/km* *(313.8 – 267.2 g/mi)*). At 1,370 revolutions per minute it already reaches its full torque of 500 Nm *(368.8 lb-ft)*, which remains constant up to 4,500 revolutions per minute. In the Audi S4, S5 Coupé and S5 Sportback it consumes only 7.3 liters of fuel per 100 kilometers *(32.2 US mpg)* as per NEDC standard, a CO_2equivalent of 166 grams per kilometer *(267.2 g/mi)*.

The crucial success actor in the efficiency of the TFSI engines is the new B cycle combustion process from Audi (see section 1.1 Synergy effects in the Group: the V engine strategy), a further development of the so-called Miller cycle. In the induction tract the intake valves close well before the piston reaches its bottom dead center. This unusually short opening time keeps the fresh gas flow comparatively small, artificially creating a smaller displacement.

When the piston moves back up again after reaching the bottom dead center, the compression phase starts later than in a conventional engine. This allows a high geometric compression ratio of 11.2:1 – the combustion takes place in a relatively small combustion chamber. Compared with the compression phase, the expansion phase has been extended, and the longer expansion of the gas increases efficiency.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

Audi supplements the Miller cycle with innovative technologies: the turbocharger presses the air into the cylinders with up to 1.5 bar of overpressure. The common-rail system injects the fuel into the combustion chamber with 250 bar of pressure; the high injection pressure ensures a homogeneous spray pattern and consequently a uniform propagation of the flame front. Because the injector lies at the center of the combustion chamber, the developers were able to realize a geometry in the area of the intake valves which in interplay with intake ports precisely swirls the incoming air – and thereby cools the walls of the combustion chamber. This prevents so-called combustion knocking, and enables Audi to achieve high compression in its TFSI engines. The quality of combustion, thermodynamic efficiency and thus engine efficiency improves as well.

Each of the four camshafts of the 3.0 TFSI can be adjusted up to a crankshaft angle of 50 degrees. At higher loads the two-stage Audi valvelift system (AVS) closes the intake valves later. The opening time increases from 130 to 180 degrees crankshaft angle, while at the same time the lift of the intake valves increases by 6.0 to 10.0 millimeters *(0.2 to 0.4 in)*. The cylinder charging also increases considerably – the 3.0 TFSI revs up powerfully with a lush output.

The turbocharger of the new 3.0 TFSI operates according to the twin scroll principle: the exhaust branches of the two cylinder banks run separately in the exhaust manifold and in the turbocharger housing, and only merge immediately in front of the turbine wheel. This technology avoids annoying interactions between the two gas columns, and thus makes a major contribution toward early and powerful torque build-up. The turbocharger is placed inside the 90 degree “V” of the cylinder banks – the exhaust side thus lies inside at the cylinder heads and the intake side outside. This layout allows a compact design and short gas flow paths with minimal loss. The 3.0 TFSI responds spontaneously and directly to the movements of the gas pedal.

Thanks to a thorough overhaul, the powerful V6 aluminum engine barely weighs 172 kilograms *(379.2 lb)*. The cylinder crankcase, manufactured from aluminum silicon alloy in the elaborate sand cast method, integrates steel cylinder liners 1.5 mm *(0.06 in)* in thickness. The so-called “deep-skirt” design extends the walls of the cylinder crankcase far downwards, which also saves weight. In combination with the newly developed rings for the aluminum pistons, this reduces friction. Assembly of the V6 in the Hungarian Győr plant employs so-called plate honing to prevent stress to the cylinder heads during their installation.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

Thermal management also contributes to the high efficiency. The crankcase and the cylinder head have separate coolant circuits. The V6 engine comes with split cooling, allowing disconnection of the cylinder crankcase circuit from the remaining engine cooling circuit. At a cold start the water pump switches off the complete coolant flow through the engine. When the operating temperature of the cylinder head is reached, the water pump turns on the water circuit through the complete engine – including the separate cylinder crankcase circuit. The latter is included only after the coolant in the cylinder crankcase reaches its limit temperature. The exhaust manifold is integrated in the cylinder head and bathed in coolant. This helps the engine to heat up quickly. When the engine is warm, this technology reduces the exhaust temperature, thereby significantly reducing fuel consumption, especially with a sporty driving style. The three-way catalytic converter is located very close to the engine and therefore reaches its operating temperature very soon.

The same applies to the spark ignition engine particulate filter, which Audi is introducing at mid-year initially in the A5 Coupé 2.0 TFSI (combined fuel consumption: 6.5 – 5.1 l/100 km* (*36.2 – 46.1 US mpg)*; combined CO_2 emissions: 148 – 117 g/km* *(238.2 – 188.3 g/mi)*) and it will be successively employed in further model series.

Other high-end technologies also contribute to the high efficiency of the new 3.0 TFSI. The fully adjustable oil pump only builds up as much pressure as necessary. The power required for the chain drive has been reduced by a new concept: the crankshaft drives the balancer shaft via gears, with the shaft lying far down in the V of the cylinder banks. From here chains run to the four camshaft sprockets. They have a tri-oval shape (slightly triangular), to compensate for power spikes and to ensure harmonious engine running. The balancer shaft rotates on low-friction roller bearings.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

1.5 High-performance engine: the new 2.9 TFSI

With the new 2.9 TFSI Audi is following on from where the legendary 2.7-liter V6 performance unit left off; the latter delivered 280 kW (380 hp) in the first RS 4 Avant (2000 through 2001). The new six-cylinder engine greatly outdoes the old one. It delivers 331 kW (450 hp) and releases a torque of 600 Nm *(442.5 lb-ft)* from 1,900 to 5,000 rpm (combined fuel consumption: 9.6 – 8.7 l/100 km* *(24.5 – 27.0 US mpg);* combined CO_2 emissions: 224 – 197 g/km* *(360.5 – 317.0 g/mi)*), catapulting the new Audi RS 5 into the sports car league: zero to 100 km/h *(62.1 mph)* in 3.9 seconds, with an optional top speed of 280 km/h *(174.0 mph).* In the NEDC cycle the 2.9 TFSI consumes 8.7 liters of fuel per 100 kilometers *(27.0 US mpg)*, equivalent to emissions of 197 grams of CO_2 per kilometer *(317.0 g/mi)*.

The new high-performance six-cylinder engine from Audi directly derives from the 3.0 TFSI. Because of the greater forces in the interior, the stroke has been shortened by 3 millimeters *(0.1 in)* to 86 millimeters *(3.4 in)*. To increase resilience, we further increased the crankshaft main bearing diameter by 2 millimeters *(0.08 in)*. The most important technological components are the same for both engines: the aluminum crankcase with steel cylinder liners, the new TFSI combustion process with central injector location and thermal management with the exhaust manifolds in the cylinder heads.

In the 2.9 TFSI the exhaust side lies in the inside V. Instead of the mono twin scroll turbocharger, two turbochargers compress the intake air, as formerly in the RS 4 engine. Each of them is responsible for a cylinder bank and builds up to 1.5 bar of boost pressure. In the intake system of the V6 biturbo, stainless steel components allow the air to flow almost unimpeded, while in the exhaust system switchable flaps modulate the sound according to the load and the driver’s request. With its growling sound, the RS 5 (combined fuel consumption: 8.7 l/100 km *(27.0 US mpg)*; combined CO_2 emissions: 197 g/km *(317.0 g/mi)*) thus recalls the engine sound of the RS 4 (B5).

* Figures depend on the tire/wheel sets used and the engine/transmission variant

1.6 Dynamic and emotive: the new Audi SQ5 3.0 TFSI

As the sportiest model of the Q5 model series, the new Audi SQ5 3.0 TFSI (combined fuel consumption: 8.5 – 8.3 l/100 km* *(27.7 – 28.3 US mpg)*; combined CO_2 emissions: 195 – 189 g/km* *(313.8 – 304.2 g/mi)*) combines powerful performance with further increased efficiency and exemplifies more than ever the emotively charged concept of the all-around SUV.

The engine
With a displacement of 2,995 cm^3, the Audi SQ5 (combined fuel consumption: 8.5 – 8.3 l/100 km* *(27.7 – 28.3 US mpg)*; combined CO_2 emissions: 195 – 189 g/km* *(313.8 – 304.2 g/mi)*) delivers a performance of 260 kW (354 hp). The turbocharged aluminum engine delivers a constant 500 Nm *(368.8 lb-ft)* of torque from 1,370 to 4,500 rpm. The sprint from zero to 100 km/h *(62.1 mph)* is completed in 5.4 seconds and the top speed is electronically governed at 250 km/h *(155.3 mph)*. In the NEDC, the new Audi SQ5 3.0 TFSI consumes just 8.3 liters of fuel per 100 kilometers *(28.3 US mpg)* – a CO_2 equivalent of 189 grams per kilometer *(304.2 g/mi)*.

New combustion process: greater efficiency
A new combustion process developed by Audi makes the 3.0 TFSI particularly efficient. It is based on the so-called “B cycle” process in combination with high-pressure injectors centrally located in the combustion chambers. With its artificially shortened compression phase, the method enables an engine process with a significantly higher base compression ratio. Combined with a power stroke that, while normal, is longer relative to the compression stroke, this allows for more efficient combustion and increased engine efficiency.

Under partial load, the Audi valvelift system enables a very short intake aperture duration of 130 degrees of camshaft angle coupled with the early closure of the intake valve. This shortens the intake phase. At higher loads, the system switches to a camshaft contour with a longer opening time and a larger valve stroke. The engine then operates with a normal compression ratio and maximum throughput.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

The turbocharger: separate exhaust columns

The turbocharger, which replaces the mechanical compressor of the previous engine, operates according to the twin-scroll principle. The exhaust branches of the two cylinder banks run separately in the exhaust manifold and in the turbocharger housing, and only merge before the turbine wheel. This technology improves the flow characteristics so that the turbine responds more spontaneously. This makes a significant contribution to the early and powerful torque build-up. The turbocharger is located within the 90-degree V of the cylinder banks. This arrangement enables compact construction and minimal flow losses, so that the 3.0 TFSI responds spontaneously and directly.

Another efficiency factor: innovative thermal management

The crankcase and the cylinder head have separate cooling circuits. After a cold start, the switchable water pump controls the flow of coolant through the engine so that the oil attains its operating temperature as quickly as possible. The exhaust manifold is integrated in the cylinder head and bathed in coolant. This helps the engine to heat up quickly. When the engine is warm, the system reduces the exhaust temperature. The result is lower fuel consumption, particularly during sporty driving.

Handling

A fast and smooth-shifting eight-speed tiptronic transmits the power in the new Audi SQ5 *(27.7 – 28.3 US mpg)*; combined CO_2 emissions: 195 – 189 g/km* *(313.8 – 304.2 g/mi)*). The lower gears feature short, sporty ratios, while the upper gears are long so as to reduce the engine speed and fuel consumption. Provided that the function is activated in Audi drive select, the transmission automatically switches to freewheeling mode as soon as the driver lifts their foot off the gas pedal at speeds between 55 and 160 km/h *(34.2 and 99.4 mph)*, ensuring even greater fuel efficiency.

The quattro permanent all-wheel drive contributes to the sporty handling. During normal driving, it distributes the engine power with a slight rear-axle bias. When necessary, the lion's share of the power is sent to the axle with the better traction. Wheel-selective torque control is active on all types of surfaces. During dynamic cornering, the software function slightly brakes the inside wheels. The car turns itself into the curve ever so slightly. Turn-in behavior remains neutral longer, and handling is stable, precise and agile.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

The optional sport differential further optimizes handling by actively distributing torque between the rear wheels via two superposition stages. When accelerating out of a narrow curve, it gives more torque to the rear wheel on the outside of the curve. This increases the agility of the Audi SQ5 even more. The sport differential literally pushes the car into the curve, nipping understeering in the bud. Its management is integrated in the Audi drive select control system, and it runs over a central control unit, the electronic chassis platform.

The sporty handling qualities of the new Audi SQ5 (combined fuel consumption: 8.5 – 8.3 l/100 km* *(27.7 – 28.3 US mpg)*; combined CO_2 emissions: 195 – 189 g/km* *(313.8 – 304.2 g/mi)*) rest on a suspension system with five-link axles at the front and rear. The complex design provides for greater stability at the limit and combines increased agility with significantly improved comfort. The standard damper control features a particularly wide spread between comfort and dynamics. The adaptive CDC dampers (continuous damping control) are integrated in the Audi drive select system along with the engine, steering, tiptronic and optional sport differential. This lets the driver control the characteristics of the engine and suspension over several modes. The S-specific adaptive air suspension is available as an option. This system allows the driver to adapt not just the damping, but also the ride height to the respective driving situation.

An important contribution to the driving dynamics of the SQ5 (combined fuel consumption: 8.5 – 8.3 l/100 km* *(27.7 – 28.3 US mpg)*; combined CO_2 emissions: 195 – 189 g/km* *(313.8 – 304.2 g/mi)*) is also the new electromechanical power steering adjustment. Optionally available is the dynamic steering, which varies its ratio depending on the speed and steering angle.

255/45 tires are mounted as standard on the equally standard 20-inch, cast aluminum wheels. 21-inch wheels are available as an option. Audi Sport offers five exclusive 21-inch wheels for further differentiation. Up front are black (optionally red), six-piston, fixed-caliper brakes with an S logo and 350-millimeter *(13.8 in)* disks.

Driver assistance systems
The Audi SQ5 also picks up the driver assistance systems from the broad, high-tech portfolio of the Audi Q5. The predictive efficiency assistant provides specific driving tips to help the driver save fuel. Adaptive cruise control (ACC) including traffic jam assist can handle some of the steering work in slow-moving traffic. Audi active lane assist makes it easier to stay in lane. The distance warning display alerts the driver when the distance to another vehicle drops below a safe distance.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

The rear cross traffic assist, the exit warning system, collision avoidance assist and turn assist are other new features to improve safety in everyday traffic. The same is true for the pre-sense systems: Audi pre sense city is standard. The system warns the driver about pedestrians and vehicles, and initiates automatic emergency braking within system limits. Park assist, the camera-based recognition of traffic signs and hill descent control round out the features.

Infotainment and Audi connect

The top-of-the-line infotainment system in the SQ5 is MMI navigation plus with MMI all-in-touch and an 8.3-inch display, which is available in combination with the tiptronic. The system recognizes handwritten input as well as touch gestures familiar from consumer electronics, such as for zooming. It also provides haptic feedback to input. One component is Audi connect, which connects the SQ5 (fuel consumption: 8.5 – 8.3 l/100 km* *(27.7 – 28.3 US mpg)*; combined CO_2 emissions: 195 – 189 g/km* *(313.8 – 304.2 g/mi)*) via LTE to the Internet. Audi connect enables convenient roaming in Europe for many connected infotainment services with its permanently installed SIM card – the Audi connect SIM with a flat-rate data package. Users can also book data packages for the Wi-Fi hotspot, which also include EU roaming.

The SQ5 (combined fuel consumption: 8.5 – 8.3 l/100 km* *(27.7 – 28.3 US mpg)*; combined CO_2 emissions: 195 – 189 g/km* *(313.8 – 304.2 g/mi)*) also offers Car2x services in the “Audi connect safety & service including security & convenience” package. In the event of an accident or breakdown, customers in an appropriately equipped vehicle receive help via the emergency call and online roadside assistance services.

Furthermore, the vehicle security & convenience services enable users to easily lock and unlock the new SQ5 via the MMI connect app on their smartphones. Customers can also check their vehicle’s status and use additional services such as Car Finder and information about the next service appointments or warning messages.

The MMI control logic offers intelligent plain text searching, among other features. The natural-language voice control function also recognizes inputs from everyday speech. In addition, the multifunctional leather steering wheel serves as a third operating level in the Audi SQ5 (combined fuel consumption: 8.5 – 8.3 l/100 km* *(27.7 – 28.3 US mpg)*; combined CO_2 emissions: 195 – 189 g/km* *(313.8 – 304.2 g/mi)*). Audi can deliver a head-up display as an optional extra. This system projects relevant information onto the windshield – including from driver assistance systems – as symbols and numbers that can be perceived quickly.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

One highlight of the display and control concept is the Audi virtual cockpit. It displays all key information in razor-sharp graphics on its 12.3-inch monitor. Possible views available include an S-specific sport mode centered on the rev counter.

The Audi phone box, another optional feature, connects the smartphone to the on-board antenna by near-field coupling and simultaneously charges it inductively using the Qi standard. The Bang & Olufsen Sound System with new 3D sound is available for hi-fi fans. The Audi smartphone interface brings Apple CarPlay and Android Auto into the car.

Body and exterior design

The length of the new Audi SQ5 (combined fuel consumption: 8.5 – 8.3 l/100 km* *(27.7 – 28.3 US mpg)*; combined CO_2 emissions: 195 – 189 g/km* *(313.8 – 304.2 g/mi)*) measures 4,671 millimeters, the width is 1,893 millimeters and the height 1,635 millimeters *(15.3 x 6.2 x 5.4 ft)*. The wheelbase is 2,824 millimeters *(9.3 ft)*. The unladen weight (without driver) of the SQ5 (combined fuel consumption: 8.5 – 8.3 l/100 km* *(27.7 – 28.3 US mpg)*; combined CO_2 emissions: 195 – 189 g/km* *(313.8 – 304.2 g/mi)*) is 1,870 kilograms *(4,122.6 lb)*. The body features an intelligent material mix of aluminum and extremely high-tensile-strength steels.

Even when stationary, an array of details underline the dynamic characteristics of the new Audi SQ5 (combined fuel consumption 8.5 – 8.3 l/100 km* *(27.7 – 28.3 US mpg)*; combined CO_2 emissions: 195 – 189 g/km* *(313.8 – 304.2 g/mi)*). The bold, sporty bumpers up front and in the rear are complemented by more strongly contoured, S-specific air inlets and the diffuser with a honeycomb grill. Another S-specific feature is the radiator grille with double aluminum slats and contrasting trim elements in matt twilight gray. The S logo with red rhombus is used in numerous locations to set additional accents.

LED technology is standard for all lighting functions. The dynamic turn signals ensure a high recognition factor. On the sides of the vehicle, aluminum-look exterior mirrors gleam and door trim strips in the body color underscore the sporty character. The rear bumper accommodates a diffuser brace in aluminum. An option exclusive to the new Audi SQ5 (combined fuel consumption: 8.5 – 8.3 l/100 km* *(27.7 – 28.3 US mpg)*; combined CO_2 emissions: 195 – 189 g/km* *(313.8 – 304.2 g/mi)*) is panther black as the exterior color.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

The interior

The dark-toned interior welcomes the driver and passengers with illuminated door sills bearing exclusive S logos. Contrasting stitching on the leather steering wheel and sport seats creates a dynamic and elegant ambiance. The S sport seats in Alcantara/leather can be upgraded to fine Nappa leather with diamond pattern and a pneumatic massage function. Brushed aluminum inlays are standard, with a variety of wood applications and an exclusive carbon inlay available as options. Aluminum-look shift paddles enable the driver to quickly shift the tiptronic's gears. The pedals and footrest have stainless steel overlays. The rear seat bench plus of the Audi SQ5 (combined fuel consumption: 8.5 – 8.3 l/100 km* *(27.7 – 28.3 US mpg)*; combined CO_2 emissions: 195 – 189 g/km* *(313.8 – 304.2 g/mi)*) is split into three segments. Longitudinal and seat back angle adjustment are optional. The luggage compartment has a basic capacity of 550 liters *(19.4 cu ft)*, which can be increased to 1,550 liters *(54.7 cu ft)* by folding down the rear seat backrests.

The equipment

The extensive standard equipment of the new SQ5 (combined fuel consumption: 8.5 – 8.3 l/100 km* *(27.7 – 28.3 US mpg)*; combined CO_2 emissions: 195 – 189 g/km* *(313.8 – 304.2 g/mi)*) in Germany includes 20-inch, cast aluminum wheels in a 5-twin-spoke star design, LED headlights and S-specific damper control. Also included are quattro permanent all-wheel drive, eight-speed tiptronic, sport seats in Alcantara/leather and a three-spoke, leather-covered multifunction steering wheel. The Audi SQ5 3.0 TFSI will arrive at retailers in Germany in mid-2017 with a base price of EUR 64,900. Production is located in the newly established plant in Mexico.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

2. Audi g-tron models with Audi e-gas: the energy revolution in the tank

Besides the classic TFSI and TDI engines, Audi is increasingly banking on alternative drive systems. Here the focus lies on the g-tron models operating with natural gas, or CNG (compressed natural gas), with the synthetically produced Audi e-gas for practically CO_2-neutral mobility.

2.1 Sporty, efficient and highly cost-effective: the Audi g-tron models

Audi is gradually expanding the range of its g-tron models: the A3 Sportback g-tron (CNG consumption: 3.6 – 3.3 kg/100 km* *(5.8 – 5.3 kg/ 100 mi)*; combined fuel consumption: 5.5 – 5.1 l/100 km* *(42.8 – 46.1 US mpg)*; combined CO_2 emissions (CNG): 98 – 89* g/km *(157.7 – 143.2 g/mi)*; combined CO_2 emissions (gasoline): 128 – 117 g/km* *(206.0 – 188.3 g/mi)*) will be joined in early summer 2017 by the A4 Avant g-tron (CNG consumption: 4.4 – 3.8 kg/100 km* *(7.1 – 6.1 kg/100 mi)*; combined fuel consumption: 6.5 – 5.5 l/100 km* *(36.2 – 42.8 US mpg)*; combined CO_2 emissions in (CNG): 117 – 102 g/km* *(188.3 – 164.2 g/mi)*; combined CO_2 emissions (gasoline): 147 – 126 g/km* *(236.6 – 202.8 g/mi)*) and the A5 Sportback g-tron (CNG consumption: 4.3 – 3.8 kg/100 km* *(6.9 – 6.1 kg/100 mi)*; combined fuel consumption: 6.4 – 5.6 l/100 km* *(36.8 – 42.0 US mpg)*; combined CO_2 emissions (CNG): 115 – 102 g/km* *(185.1 – 164.2 g/mi)*; combined CO_2 emissions (gasoline): 144 – 126 g/km* *(231.7 – 202.8 g/mi)*). Used as fuel in the models, the climate-neutral Audi e-gas absorbs exactly the same amount of CO_2 as that emitted by the car.

The **Audi A5 Sportback g-tron** (CNG consumption: 4.3 – 3.8 kg/100 km* *(6.9 – 6.1 kg/100 mi)*; combined fuel consumption: 6.4 – 5.6 l/100 km* *(36.8 – 42.0 US mpg)*; combined CO_2 emissions (CNG): 115 – 102 g/km* *(185.1 – 164.2 g/mi)*; combined CO_2 emissions (gasoline): 144 – 126 g/km* *(231.7 – 202.8 g/mi)*) is driven by a 2.0 TFSI engine with the highly efficient “B cycle” combustion process developed by Audi. The pistons and valves have been specially modified for gas operation and allow for an optimal compression ratio.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

The turbo engine extended to allow CNG operation thus outputs 125 kW (170 hp). Its maximum torque of 270 Newton meters *(199.1 lb-ft)* is available at 1,650 revolutions per minute. An electronic controller reduces the high pressure of the compressed natural gas (CNG) flowing from the tank from as much as 200 bar to a working pressure of 5 to 10 bar in the engine. This pressure control function is performed dynamically and precisely in response to the power requested by the driver. The correct pressure is always present in the gas line and at the injector valves – low pressure for efficient driving in the lower speed range, and higher pressure for more power and torque.

Altogether, Audi engineers have achieved unparalleled efficiency in CNG engines through these measures. In the NEDC cycle, the Audi A5 Sportback g-tron with S tronic consumes merely 3.8 kg of CNG per 100 kilometers *(6.1 kg/100 mi)*. This corresponds to a fuel cost of around EUR 4.00 (as of May 2017). CO_2 emissions are about 102 grams per kilometer *(164.2 g/mi)*. In gasoline operation, the model uses 5.6 liters per 100 kilometers *(42.0 US mpg)* and 126 grams of CO_2 per kilometer *(202.8 g/mi)*. The values for the manual transmission version are 4.0 kilograms CNG per 100 kilometers *(6.4 kg/100 mi)* with 108 grams CO_2 emitted per kilometer *(173.8 g/mi)* in gas mode and 5.9 liters per 100 kilometers *(39.9 US mpg)* and 135 grams CO_2 per kilometer *(217.3 g/mi)* in gasoline mode. The optional seven-speed S tronic accelerates the five-door model from zero to 100 km/h *(62.14 mph)* in 8.4 seconds and on to a top speed of 224 km/h *(139.2 mph)*; with the six-speed manual transmission the figures are 8.5 seconds and 226 km/h *(140.4 mph)*.

The same drive concept forms the basis of the **Audi A4 Avant g-tron** (CNG consumption: 4.4 – 3.8 kg/100 km* *(7.1 – 6.1 kg/100 mi)*; combined fuel consumption: 6.5 – 5.5 l/100 km* *(36.2 – 42.8 US mpg)*; combined CO_2 emissions in (CNG): 117 – 102 g/km* *(188.3 – 164.2 g/mi)*; combined CO_2 emissions (gasoline): 147 – 126* *(236.6 – 202.8 g/mi)*). Its 2.0 TFSI engine also accelerates the S tronic model from zero to 100 km/h *(62.14 mph)* in 8.4 seconds. Top speed is 221 km/h *(137.3 mph)*. The manual transmission version sprints to freeway speed in 8.5 seconds and attains a top speed of 223 km/h *(138.6 mph)*. The fuel consumption and emission levels are also nearly identical to those of the A5 Sportback g-tron: with the optional S tronic, it consumes 3.8 kilograms of CNG per 100 kilometers *(6.1 kg/100 mi)* with 102 grams CO_2 emitted per kilometer *(164.2 g/mi)*; the manual transmission version uses 4.0 kilograms of CNG *(6.4 kg/100 mi)* and emits 109 grams CO_2 per kilometer *(175.4 g/mi)*.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

In gasoline mode these levels are: 5.5 liters per 100 kilometers *(42.8 US mpg)* and 126 grams CO_2 per kilometer *(202.8 g/mi)* in the automatic version and 6.0 liters per 100 kilometers *(39.2 US mpg)* and 136 grams CO_2 per kilometer *(218.9 g/mi)* with manual transmission.

Compared with gasoline, combustion of natural gas emits 25 percent less CO_2 due to the lowest carbon content of all hydrocarbons. Particulate emissions also remain very low. When operated with sustainably produced Audi e-gas, which is practically identical chemically to high-quality natural gas and can therefore be fed into the natural gas grid in arbitrary amounts, the g-tron fleet is practically climate-neutral on the road in well-to-wheel terms. The CO_2 balance sheet is lower by 80 percent** relative to a comparable gasoline model.

In the NEDC cycle, the bivalent g-tron model with its tank capacity of 19 kilograms of gas *(41.9 lb)* (at 15 degrees Celsius) drives up to 500 kilometers *(310.7 mi)*. When the pressure in the tank falls below 10 bar with about 0.6 kilograms (*1.3 lb*) of gas remaining, the engine management automatically switches to gasoline operation. In this mode, the A4 Avant g-tron (CNG consumption: 4.4 – 3.8 kg/100 km* *(7.1 – 6.1 kg/100 mi)*; combined fuel consumption: 6.5 – 5.5 l/100 km* *(36.2 – 42.8 US mpg)*; combined CO_2 emissions in (CNG): 117 – 102 g/km* *(188.3 – 164.2 g/mi)*; combined CO_2 emissions (gasoline): 147 – 126 g/km* *(236.6 – 202.8 g/mi)*) and the A5 Sportback g-tron (CNG consumption: 4.3 – 3.8 kg/100 km* *(6.9 – 6.1 kg/100 mi)*; combined fuel consumption: 6.4 – 5.6 l/100 km* *(36.8 – 42.0 US mpg)*; combined CO_2 emissions (CNG): 115 – 102 g/km* *(185.1 – 164.2 g/mi)*; combined CO_2 emissions (gasoline): 144 – 126 g/km* *(231.7 – 202.8 g/mi)*) can cover a further 450 kilometers *(279.6 mi)*. After refueling (for the purpose of analyzing the quality of the gas used) and in extremely cold conditions, the engine is initially started using gasoline. It then changes as quickly as possible to gas mode. All such switch-overs take only a few tenths of a second and occur practically imperceptibly.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

** In pure gas mode (CNG) with a well-to-wheel analysis (a life cycle assessment that includes fuel production and normal driving of the automobile), in comparison with an equivalent model in the same performance class with a conventional gasoline engine

2.2 Uncompromisingly safe: the CNG tanks

Audi has installed the four cylindrical CNG tanks as a compact module in the rear section of the A4 Avant g-tron (CNG consumption: 4.4 – 3.8 kg/100 km* *(7.1 – 6.1 kg/100 mi)*; combined fuel consumption: 6.5 – 5.5 l/100 km* *(36.2 – 42.8 US mpg)*; combined CO_2 emissions in (CNG): 117 – 102 g/km* *(188.3 – 164.2 g/mi)*; combined CO_2 emissions (gasoline): 147 – 126 g/km* *(236.6 – 202.8 g/mi)*) and the A5 Sportback g-tron (CNG consumption: 4.3 – 3.8 kg/100 km* *(6.9 – 6.1 kg/100 mi)*; combined fuel consumption: 6.4 – 5.6 l/100 km* *(36.8 – 42.0 US mpg)*; combined CO_2 emissions (CNG): 115 – 102 g/km* *(185.1 – 164.2 g/mi)*; combined CO_2 emissions (gasoline): 144 – 126 g/km* *(231.7 – 202.8 g/mi)*). They are optimized for the available space, and each is specifically sized. Sheet steel shells with tensioning straps hold the cylinders and protect them against damage, for example from the edges of curbs. The complete CNG tank module, which also includes the 25 liter *(6.6 US gal)* gasoline tank, is fitted during production of the g-tron models. The spare wheel well has been eliminated. The battery has also moved from the luggage compartment to the engine compartment. The loading floor is level with the loading lip, thus offering a full-fledged luggage compartment. The filler necks for gas and gasoline are located under a common tank flap. Two indicators inform the driver about the fill levels of the tanks. The driver information system shows the fuel consumption in the active operating mode.

The CNG tanks storing the gas with an operating pressure of 200 bar at 15 degrees Celsius follow the Audi lightweight design philosophy. Thanks to their innovative layout, they weigh 56 percent less than comparable steel cylinders. Their inner layer is a gas-tight matrix of polyamide. The second layer, a composite winding of carbon fiber-reinforced polymer (CFRP) and glass fiber-reinforced polymer (GFRP), provides maximum strength. The third layer is pure GFRP and serves primarily as a visual inspection aid, turning milky white where damaged. Before being installed in a car, each tank is tested at 300 bar during production. The actual bursting pressure is much higher still and far exceeds the legal requirements.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

2.3 Virtually carbon-neutral driving: Audi e-gas

Practically carbon-neutral driving – already possible today with Audi e-gas. The fuel is produced from water and carbon dioxide with green electricity or from recyclable materials, such as straw and green waste. The fuel does not depend on mineral oil, emits only as much CO_2 in the exhaust as it absorbed during manufacture, and does not compete with food production.

Audi offers this fuel for three years as a standard feature to customers ordering a g-tron model by May 31, 2018. With this deal, the brand is reducing the CO_2 emissions of the g-tron fleet when running on gas by 80 percent**. Customers can fill up their g-tron models at any CNG fueling station and pay the regular price. By feeding the computed volume of Audi e-gas into the natural gas grid, Audi ensures the green benefits of the program, including the corresponding reduction in CO_2 emissions. This occurs automatically on the basis of surveys and service data from the cars. TÜV Süd, a German testing and certification corporation, monitors and certifies the process. Our g-tron customers receive a document that confirms their car will be supplied with Audi e-gas and informs them about the certification.

Audi obtains the e-gas from its own power-to-gas facility in Werlte in Lower Saxony (Emsland), among other places. In operation since 2013, the plant produces up to 1,000 tons of e-gas per year, absorbing up to 2,800 tons of CO_2. This quantity enables around 1,500 Audi g-tron models to drive 15,000 kilometers *(9,320.6 mi)* each year virtually CO_2-neutrally.

The Audi e-gas system produces the renewable fuel in two major steps – electrolysis and methanation. In the first step, the plant uses renewably generated electricity to split water into oxygen and hydrogen. In the medium term, the latter can also serve as a fuel for fuel cell cars.

The absence of any universal hydrogen infrastructure at present means that the focus today lies on the second process step: the hydrogen reacts with CO_2 coming from a nearby waste biogas plant, to produce synthetic methane, or Audi e-gas.

Almost identical chemically to fossil natural gas, it is fed into the European gas grid and compensates for the volume of natural gas used by the g-tron model in the New European Driving Cycle (NEDC).

* Figures depend on the tire/wheel sets used and the engine/transmission variant

** In pure gas mode (CNG) with a well-to-wheel analysis (a life cycle assessment that includes fuel production and normal driving of the automobile), in comparison with an equivalent model in the same performance class with a conventional gasoline engine

2.4 Potential: expansion of the CNG grid and new production methods

The Audi e-gas plant in Werlte demonstrates just how well the power-to-gas concept – the conversion of electricity into fuel – works. Power-to-gas plants allow storage of surplus renewable energy, thereby making a valuable contribution to the energy transition. At the same time, the Audi e-gas plant helps stabilize the power grid at high feed-in rates of renewable energy. This makes Audi technology both a part and a driver of the energy revolution.

In view of the growing g-tron fleet, Audi is expanding its e-gas capacities through new cooperative arrangements. Our partners are the Thüga Group and Viessmann GmbH. The latter is working on a biological rather than chemical methanation process. Audi also obtains methane from certified residual material biogas plants that meet strict sustainability criteria.

In early May, the Volkswagen Group, fueling station operators and gas grid operators announced the signing of a joint declaration of intent on expanding CNG mobility. The goal is, together with other automakers, to expand the CNG fleet in Germany tenfold to one million units by 2025. At the same time, the fueling station network in the German Federal Republic is to be expanded from currently 900 to 2,000 locations by 2025. In other European countries, too, the consortium intends to press ahead with the expansion in compliance with the requirements of EU Directive 2014/94 (deployment of alternative fuels infrastructure).

Besides the e-gas project, Audi is conducting research on other sustainable fuels: the Audi e-fuels. Audi e-diesel, Audi “e-benzin” (e-gasoline) and Audi e-ethanol are synthetic fuels of the latest generation. In the case of all these fuels, their production absorbs the quantity of CO_2 emitted by the car during operation – the carbon dioxide is recycled. The driving force in the production of e-fuels is renewable energy.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

3. Test cycles and emission regulations

For over 20 years, the consumption and emission levels of passenger cars have been determined in the New European Driving Cycle (NEDC). In September 2017, the WLTP (Worldwide Harmonized Light Duty Test Procedure) will supersede the previous measurement procedure. The aim is to represent more realistic data in keeping with the new traffic and driving conditions in Europe. At the same time, emission measurements in actual road traffic are required (RDE = Real Driving Emissions). The new Euro 6c emission standard is also going into effect.

3.1 New European Driving Cycle (NEDC)

Since the introduction of the standardized European emissions regulations in 1996, a standardized driving cycle (New European Driving Cycle, or NEDC) has been the basis for determining vehicle emission levels within the European Union. The EU Commission and the UN Economic Commission for Europe (UNECE) developed NEDC in the 1990s with the aim of providing a uniform standard for consumers and policy-makers in Europe. It serves as the basis for proof of compliance with the legal limits on pollutants and for the determination of official consumption levels and CO_2 emissions from passenger cars and light commercial vehicles. The electrical driving range of plug-in hybrid models and electric cars is also based on the NEDC.

The NEDC is performed on a dynamometer and consists of two parts: after a cold start of the engine, urban driving is simulated for 13 minutes – with multiple acceleration and braking as well as periods of stopping. The average speed in this segment of the cycle is 18.8 km/h *(11.7 mph)*, which is roughly equivalent to conditions in commuter traffic. This is followed by simulation of intercity driving for 400 seconds, during which time the car attains a top speed of 120 km/h *(74.6 mph)*. During the measurement, the shift points (in the case of manual transmission) and the driving resistance as well as the test mass in the form of flywheel mass categories are precisely defined.

As of September 1, 2015, the rolling resistance of the tires is included, while the influence of special equipment or electrical consumers remains neglected. The NEDC describes not only the driving profile, but also the measurement and ambient conditions. It specifies, for example, how a vehicle is to be loaded during the measurement and the temperatures at which the measurement is to occur. This standardized definition of measurement conditions allows objective comparability of the measurement results.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

Since a standardized test cycle like the NEDC captures the variety of possible operating conditions and different driving profiles only to a limited extent, actual road traffic may present deviations from the NEDC list of values. The NEDC also does not take into account settings like an activated air conditioning system, other switched-on consumers or the individual vehicle configuration with optional equipment.

3.2 WLTP

On September 1, 2017, the WLTP (Worldwide Harmonized Light Duty Test Procedure) will supersede the NEDC as the procedure for measuring consumption levels. WLTP is intended as a standardized test procedure for passenger cars and light commercial vehicles and represents the emission levels and fuel consumption rates more realistically than previously. In late May 2017 the EU Member States are to receive a corresponding recommendation, which will be implemented legally and which will be binding for tax purposes by 2018 at the earliest. During the transitional phase from September 1, 2017, to January 1, 2019 (country-specific deviations possible), the NEDC values (or the NEDC values correlated from the WLTP measurement) will continue to form the basis of taxation for customers.

Unlike the NEDC, the WLTP is much more dynamic: its defined driving profiles contain significantly more acceleration and braking events (four phases: up to 60, 80, 100 and 130 km/h *(37.3, 49.7, 62.1 and 80.8 mph)*). As a result, different driving situations – from urban to freeway driving – are thus represented. The maximum speed in the WLTP driving cycle is 131 km/h *(81.4 mph)*, which is 10 km/h *(6.2 mph)* higher than with the NEDC. The new test cycle also exceeds the old one both in duration (30 minutes) and in average speed (46.6 km/h *(29.0 mph)*). The circuit traveled on the dynamometer corresponds to around 23 kilometers *(14.3 mi)* instead of 11 kilometers *(6.8 mi)* as previously, and the temperature of the test chamber is 23°C *(73.4°F)*.

With the Ambient Temperature Correction Test the procedure takes into account the influence on consumption by the average ambient temperature of 14°C *(57.2°F)* on a vehicle parked for over 9 hours, as stipulated by the EU.

WLTP takes into account the effects of customer-specific optional equipment on weight, aerodynamics and vehicle electrical system power consumption (quiescent current). Comfort consumers such as the air conditioning and seat heating are switched off during the measurement as before with the NEDC.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

Other innovations concern the shift points (for manual transmissions): they are no longer statically specified, but computed as a function of vehicle parameters like engine power and transmission gear ratio.

All new type-approved engines and models must have their emissions and consumption levels WLTP-tested as of September 1, 2017, and all new vehicles as of September 1, 2018.

	NEDC	WLTP
Driving time	approx. 20 minutes (1,180 s)	30 minutes (1,800 s)
Circuit length	11.007 km *(6.8 mi)*	23.25 km *(14.4 mi)*
Top speed	120 km/h (*74.6 mph*)	131 km/h *(81.4 mph)*
Average speed	33.6 km/h *(20.9 mph)*	46.6 km/h *(29.0 mph)*
Stopped share	25% / 14 stops (280 s)	13% / 9 stops (226 s)
Optional equipment included	no	yes
Shift points	specified according to speed	individually

3.3 RDE and PEMS measurements

RDE stands for Real Driving Emissions. In addition to the new WLTP test cycle on the dynamometer, emission tests in actual traffic conditions are required in Europe as of September 1, 2017. The RDE test procedure is performed by means of portable emissions measurement systems (PEMS): the PEMS measurement box connected to the exhaust system of the vehicle measures the nitrogen oxide and carbon monoxide emissions and records a variety of engine, vehicle and environmental parameters along the predefined route. The continual comparison against GPS data then yields a precise correlation between driving situations and exhaust characteristics.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

The route for an RDE measurement contains numerous arbitrary acceleration and braking events, with the travel time taking between 90 and 120 minutes, depending on traffic conditions and the driving style. The conformity factor (CF) indicates the maximum by which the gaseous emissions measured on the road may exceed the value determined in the WLTP method under laboratory conditions. The first stage, during a transitional period beginning in September 2017, will have a CF of 2.1 for NOx emissions and 1.5 for the PN (particulate number). The second stage, beginning in January 2020, will set the factor at a maximum of 1.5.

The RDE measurement does not take into account the complex thermal behavior of the combustion engine. The consumption and emission levels vary according to the operating mode. For example, in a cold start and at full load they will be higher than with a warm engine and while gliding along in traffic. The measurement results also greatly depend on the individual person's driving behavior. The conformity factor takes into account the dispersion by the boundary conditions of the measurements, which is why a CF of 2.1 is difficult to attain. To comply with the new limits, gasoline engines must be fitted with particulate filters. Their first use at Audi is slated for the Audi A5 Coupé 2.0 TFSI from June 2017 and they will later be gradually extended to all other series. In the future, Audi will be conducting all consumption and emission measurements with spark ignition engine particulate filters, as in accordance with the RDE legislation.

3.4 New Euro 6c emission standard

Since 1991 the European emission standard has been in effect, which in the past few years has gradually lowered the limits for emissions from cars and trucks. Separate limits apply to spark ignition and diesel engines, respectively. Regulated are the so-called limited exhaust components, such as nitrogen oxide (NO_x) emissions and the number of particles emitted.

The Euro 6c standard goes into effect on September 1, 2017, for newly type-approved vehicles and on September 1, 2018, for newly registered cars. Besides the conversion from NEDC to the WLTP procedure and RDE measurements, the most important difference compared with the current Euro 6b standard is the particulate number (PN) for spark ignition engines. In the future, it may not exceed one-tenth of the previous value. The introduction of Euro 6c will also tighten the threshold values for on-board diagnostic systems (OBD). The greatest influence on fuel consumption is still exerted by the driver – through his or her own driving style.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

4. Versatile and efficient: mild-hybrid technology

Audi is pressing ahead with the electrification of its drive systems across a broad front. In mid-2017, the new mild-hybrid drive vehicles (MHEVs) will start joining the product line. The next generation of luxury sedans, the Audi A8, will have them on board – in the 48-volt version – regardless of engine type.

The new technology is suitable for the interplay with either diesel or gasoline engines and can reduce consumption of a V6 gasoline engine by up to 0.7 liters per 100 kilometers *(0.2 US gal per 62.1 mi)* during customer operation, for example. Unlike other efficiency technologies within the engine, the MHEV drives increase ride comfort, since they allow silent coasting within larger speed ranges up to a maximum speed of 160 km/h *(99.4 mph)*.

Audi offers the MHEV drives in two variants. For the four-cylinder engines they are based on the familiar 12-volt electrical system. The six-cylinder and eight-cylinder engines, as well as the W12 cylinder units, will receive a new 48-volt system generally serving as the main vehicle electric system. In particular, this technology offers many ways for making driving more efficient, sportier and more comfortable in the future.

At the 2017 Geneva Motor Show the brand presented the potential of its new technologies in the form of the Audi Q8 sport concept showcar. Its 48-volt electrical system integrates a further developed MHEV system as well as an electric-powered compressor (EPC). Together the two components provide a new level of dynamics. The efficiency is also significantly increasing – at low speeds as in parking, the showcar can even be driven electrically.

4.1 MHEV: operation

The mild-hybrid drive from Audi in the new A8 comprises two central components. One of them is a water-cooled belt alternator starter (BAS) on the front side of the engine. A heavy-duty V-ribbed belt connects it to the crankshaft. The BAS yields a recuperation level up to 12 kW and 60 Nm *(44.3 lb-ft)* of torque.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

The second component is a lithium-ion battery with 10 Ah charge capacity and a constant voltage of 48 volts. In the new large sedan, the newly developed 48-volt power system serves as the main vehicle electrical system. The 12-volt system is connected to the main electrical system via a DC/DC converter. Located in the luggage compartment, the lithium-ion rechargeable battery has about the size of a large lead battery. Controlled air cooling provides the thermal management.

The 48-volt-based MHEV technology is particularly more comfortable and efficient. If the driver takes his foot off the accelerator at a speed between 55 and 160 km/h *(34.2 to 99.4 mph)*, the car can coast for up to 40 seconds with the engine off completely. During slow coasting, the start-stop phase already begins at 22 km/h *(13.7 mph)*.

Once the driver accelerates again – whether from a stop or while driving – the vehicle restarts quickly and very comfortably: the BAS revs up the internal combustion engine to the target speed, then injection occurs again and, in the case of a gasoline engine, ignition. While the conventional pinion starter remains on board, it practically comes into play only at the initial starting, if the engine oil is still cold and viscous. In such a situation, the belt of the BAS could slip through.

In many situations, recuperation – recovery of energy during deceleration – is more efficient than coasting. To decide between the two, the drive management system in the new Audi A8 uses the front camera and, optionally, data from the predictive efficiency assistant, the route data stored in the navigation system and other data supplied by the highly networked sensor set. The bottom line is that the mild-hybrid drive achieves fuel savings of up to 0.7 liters per 100 kilometers during customer operation (with the V6 TFSI).

Audi also offers the new MHEV technology with the conventional 12-volt electrical system. In this configuration, it interacts with the 2.0 TFSI engine. The functional principle is the same as with 48 volts, although the coasting phases, recuperation output and the CO_2 savings are somewhat smaller.

4.2 Broad base: 48-volt vehicle electrical system

In a different layout – without MHEV – the 48-volt constant voltage system already entered volume production in 2016 as the Audi SQ7 TDI. In this vehicle, the alternator still operates on a 12-volt basis, and a DC converter couples the 48-volt electrical subsystem. It in turn supplies the electric-powered compressor (EPC) for the V8 diesel as well as the electromechanical active roll stabilization (eARS).

* Figures depend on the tire/wheel sets used and the engine/transmission variant

The EPC supports the two turbochargers of the 4.0 TDI engine with up to 7 kW of power whenever they cannot draw enough energy from the exhaust stream. The power is immediately available when the driver accelerates – the experience is particularly impressive when starting off. The eARS is another innovation from Audi. Its centerpiece is an electric motor that uncouples the two halves of the stabilizer when driving straight ahead. The result is excellent ride comfort. During sporty driving along bends, the electric motor turns the tubes towards one another, for greater tautness in handling.

Audi is now taking great strides in introducing the 48-volt and MHEV technologies into volume production. In a few years, other Audi model series will also be receiving the new mild hybridization scope. The new architectures allow the realization of even greater power and torque, and innovative features will enable greater fuel savings. In the medium term, the brand plans to convert ancillary units like pumps and compressors to 48 volts, they will then be able to be more precisely controlled according to requirements, as well as them having a lighter and more compact construction. The same applies to large static convenience consumers such as window heating or sound systems. Small consumers such as control units or lights will remain in the 12-volt system well into the future, however.

4.3 Electrical coasting, powerful boosting: Audi Q8 sport concept

The brand has demonstrated the great potential of MHEV systems with its Audi Q8 sport concept car, which made its debut at the 2017 Geneva Motor Show. Located between the crankshaft and transmission, the starter alternator outputs 20 kW and 170 Nm *(125.4 lb-ft)*. During deceleration, the powerful MHEV system can recover a high measure of energy and feed it back into the lithium-ion battery. At low speeds, it can drive the sports SUV by itself. Boosting by the internal combustion engine, a 3.0 TFSI, affords a total of up to 700 Nm (*516.3 lb-ft*).

The 48-volt system of the Audi Q8 sport concept features an electric-powered compressor (EPC) in addition to the integrated starter alternator. It closes the turbo lag and allows for a large and powerful mono twin scroll turbo. With a system output of 350 kW (476 hp), the showcar accelerates from zero to 100 km/h *(62.1 mph)* in 4.7 seconds, and presses ahead to a top speed of 275 km/h *(170.9 mph)*. The MHEV system lowers fuel consumption of the concept car by approximately one liter per 100 kilometers.

* Figures depend on the tire/wheel sets used and the engine/transmission variant

Further information on official fuel consumption figures and the official specific CO_2 emissions of new passenger cars can be found in the “Guide on the fuel economy, CO_2 emissions and power consumption of all new passenger car models,” which is available free of charge at all sales dealerships and from DAT Deutsche Automobil Treuhand GmbH, Hellmuth-Hirth-Str. 1, 73760 Ostfildern-Scharnhausen, Germany (*www.dat.de*).

* Figures depend on the tire/wheel sets used and the engine/transmission variant